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AIRPLANES AND GEOGRAPHY*

By Willis T. Lee
United States Geological Survey

The airplane opens a new world to the geographer, for some parts of the earth's surface can be conveniently observed and adequately illustrated in no other way than from the air. Aerial photography is therefore a new and powerful aid in the study of physical geography.[1] It is well known that aerial photography was used in many ways during the World War. A vast fund of information accumulated then is now available for use in various ways.[2] Aerial photography is obviously of particular value in the exploration and representation of areas that are inaccessible or accessible only with difficulty by ordinary methods, such as some parts of the Coastal Plain of Virginia, Maryland, and Delaware.

General View of the Geography of the Coastal Plain

For the purpose of testing the utility of the airplane for observing country of this character a flight of 200 miles or more was made over parts of eastern Virginia. From Langley Field we rose to an altitude of 3,000 feet, then flew southward over Hampton Roads, Norfolk, and the Dismal Swamp. At Lake Drummond we turned northwestward, passing over Suffolk to James River, which we followed upstream to its great meanders. There we turned northeastward, passing over West Point to the mouth of Rappahannock River, and then followed the shore of Chesapeake Bay southward to Langley Field.

The general impression gained from this flight was much the same as that gained by looking down on a map spread on a table. There was no difficulty in recognizing the objects mapped, such as villages, streams, and roads. Even details like the color of the soil appeared startlingly clear, and it was easy to distinguish the well-cultivated from the weedy fields. Town houses and streets appeared as if laid off by a draftsman's rule. The great complicated framework of steel beams at the Newport News shipyards looked like filigree, but the thousands of men at work could not be seen. Many ocean-going vessels lay at anchor in Hampton Roads, but from our lofty point of view they seemed to be as small as rowboats.

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*This paper is published by permission of the Director of the United States Geological Survey. It is based on observations made possible by the co-operation of officials of the air services of the War and Navy departments. The assistance of Captain Walter R. Lawson, operations officer, and Captain Fred Place, director of the School of Aerial Photography, at Langley Field, is gratefully acknowledged. These officers placed at my disposal their entire collection of photographs, from which many were selected for illustration, both in this paper and in the forthcoming geographic handbook to be published by the United States Geological Survey. Some of the photographs used here were made by Captain Place for this particular purpose. Captain Lawson also interested himself in the investigation and personally piloted me in flights in order to point out particularly good examples of submerged land forms which he had observed. Later, officials of the Navy Air Service at Washington, D. C., extended similar privileges, and I was able to obtain views of the underwater channels and drowned terraces of the Potomac.

[1] The development of aerial photography has been admirably summed up by Herbert E. Ives: Airplane Photography, J. B. Lippincott Co., Philadelphia, 1920.

[2] Compare E. Lester Jones: The Aeroplane in Surveying and Mapping, *Flying*, June, 1919, pp. 438–441, 472.

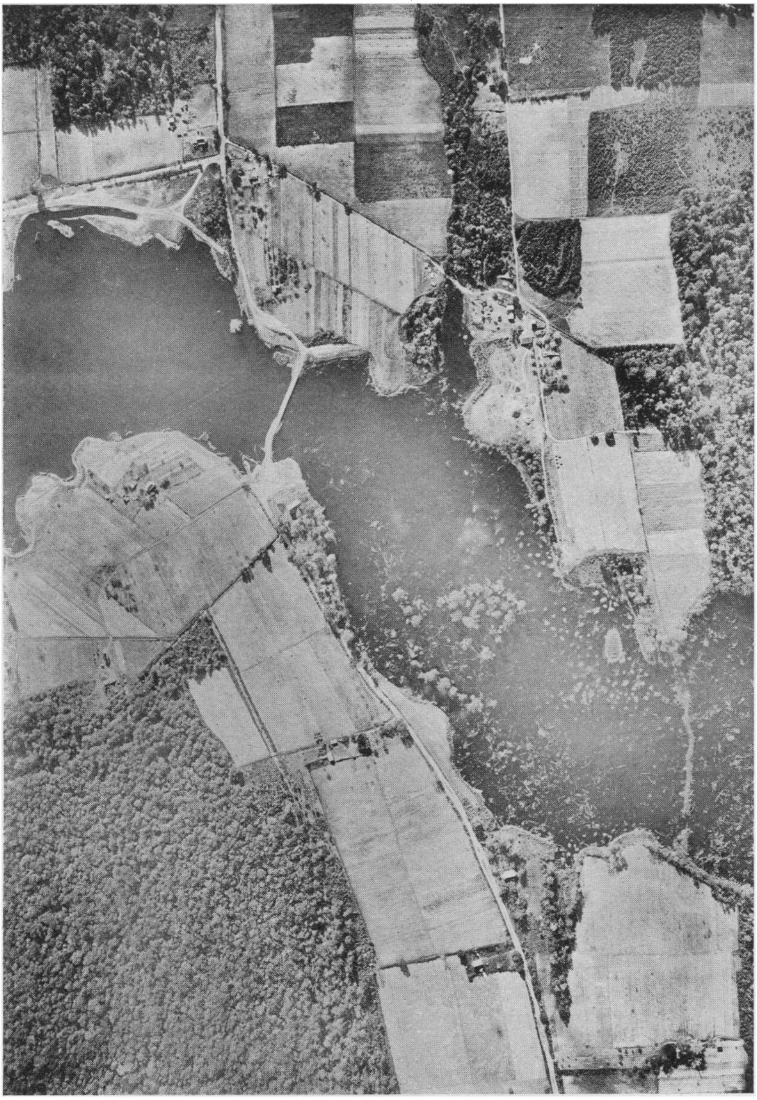


Fig. 1—Vertical view of Big Bethel Reservoir near Langley Field, Va., showing roads, bypaths, and buildings; water in which drowned trees are still standing; cultivated lands (the light-colored plats having parallel ridges); forests and brush-covered lands. (Photograph by U. S. Army Air Service.)

The smoke from Norfolk obscured our vision somewhat while we were over that city, but with our rate of 100 miles an hour we soon emerged from it to find ourselves over Dismal Swamp, which had the appearance of a vast dark-colored monotonous plain. Lake Drummond, the central body of water in this swamp, had the general aspect of a great hole in the plain rather than that of a body of water. Although the water of the lake is dark brown, like the water of the southern swamps generally, the lake bottom was dimly visible. It differed but little in color from the surrounding forest-covered land except that it was mottled with light areas of irregular shape. The general appearance of the lake basin reminded me of the photographs of lunar craters. The Nansemond scarp where the forested swamp gives place to the tilled fields of the higher lands to the west was clearly recognized. Still farther west the country consists chiefly of wooded valleys, "pocosons," and forested plain with here and there a clearing. Near the main streams, however, the flat lowlands are generally cleared and cultivated.

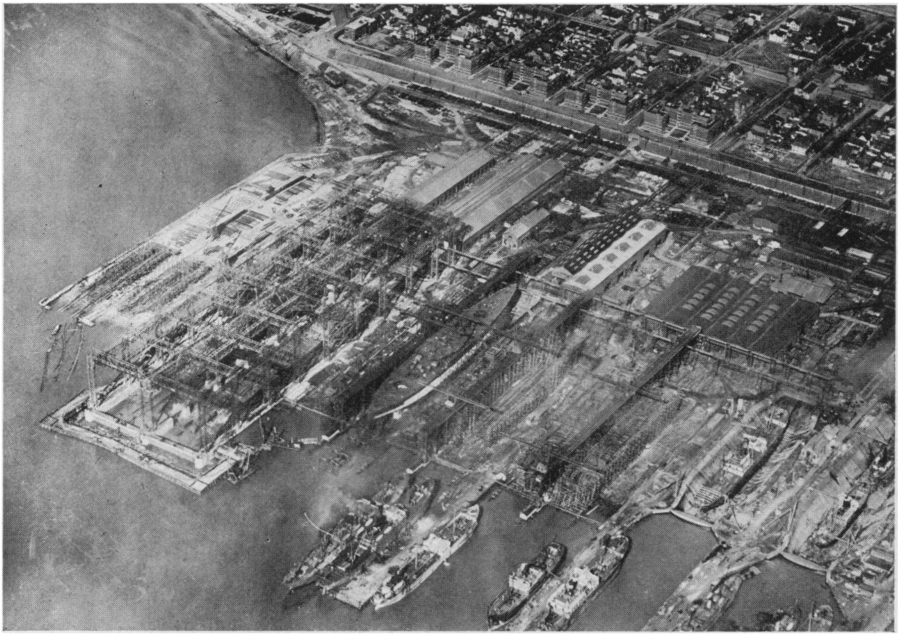


FIG. 2—Newport News, Va., showing city blocks and shipyards with partly completed vessels on ways, in dry dock, and at wharf. (Photograph by U. S. Army Air Service.)

RESULTS OF TRIAL FLIGHT

So much was gained from this trial flight and so vast seemed the possibilities of obtaining, by means of the airplane, new information on the physical geography of the low-lying areas of the Coastal Plain that other flights were made, some for observation and others for obtaining photographs. Some of these flights were made over land, others over water, and still others over such strange middle ground between land and water as the tidal marshes, mud flats (see Fig. 6), and drowned lowlands. Some of the more significant observations relating to these flights and to the uses of aerial photography are here recorded. They may be grouped under the following headings:

1. Observations in well-known areas, such as a city, in which there are many details to be shown.
2. Observations in areas such as a marsh, in which many of the details may be unimportant and are usually omitted from maps and descriptions, because the difficulty of obtaining them by ordinary methods is too great to warrant the necessary expenditure of time and money.
3. Observations in submerged areas, where information as to the under-water surface has been obtained heretofore chiefly by soundings.

DETERMINATION OF DETAILS IN WELL-KNOWN AREAS

It is not the function of this paper to discuss the application of aerial photography to the making of maps, except in so far as maps are incidental to geographic study. But the interests of the map maker and the student of geography are so nearly identical that it is difficult to omit all references to mapping. In fact, the country as seen from a plane high in the air has a striking resemblance to a map. For this reason aerial photographs properly taken and properly interpreted make excellent maps. But just as the reader of a map must know the meaning of the symbols used on the map, so the user of aerial photographs must learn to interpret them. For example, when a photographic print is so oriented that shadows point toward the observer, hollows and hills, buildings and trees appear natural. If the print is reversed, hills may have the appearance of hollows. By practice the observer soon learns distinctive characteristics. Forests are readily distinguished from brush lands, and even the kinds of trees may be recognized by their characteristics of growth. Orchards may be recognized by the even spacing of the trees. Paved roads may be distinguished from secondary roads and byways. Bridges, fords, and a great variety of small objects may be recognized by some distinctive peculiarity.

It is well known that the accurate mapping of a tract which contains many details that are to be shown is very expensive. The cost of really accurate representation on a map of all buildings, streets, and alleys of a city, such as Newport News (see Fig. 2), is almost prohibitive. It is certain that aerial photographs properly oriented by means of points in the photographed area whose locations are accurately determined by the ordinary methods of surveying would supply much of the desired information at less expense. Experiments are now in progress to determine relative costs, as well as better modes of procedure. Aerial photography may also be of use in keeping maps and charts up to date, especially in areas where changes occur frequently, and in supplying details for places difficult to traverse.

Photographs are useful also in an area where it is desirable to show accurately certain details of open country, such as forested areas, tilled lands, and the quality of roads. This can perhaps be best illustrated by an example.

Mapping of the Camp Abraham Eustis Area, Virginia

The excellent topographic maps of parts of eastern Virginia recently completed by the United States Geological Survey show among other things the general distribution of forests with somewhat indefinite outlines. This is perhaps all that is warranted for most areas, but there are places where more accurate information is needed. It might be desirable to know whether an area mapped as forest is covered with large timber or with worthless brush; whether the forest consists of evergreen or deciduous trees; whether the cleared land is cultivated, pasture land, or overgrown with bushes; whether the roads are well-kept thoroughfares or unfrequented byways. It is important to aviators that maps of areas that lie along airplane routes show cleared tracts where landings can be made in safety. Investigations were carried on in eastern Virginia during the war to determine these and other characteristics of the country, for the purpose of coast

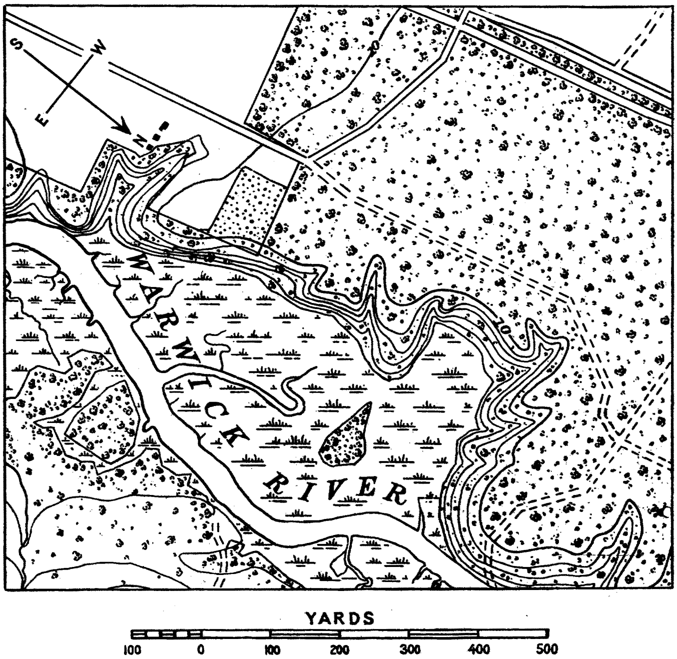


FIG. 3—A part of Camp Abraham Eustis, Va., showing the mapped area represented by the photographs shown in Figs. 4 and 5. Streams, swamps, woodlands, and clearings are seen. The contour interval is 2 meters; scale 1:10,000. Orientation corresponds with that of Fig. 4. (Drawn from Mulberry Island Sheet, No. 2, Corps of Engineers, U. S. Army, Special Military Map.)

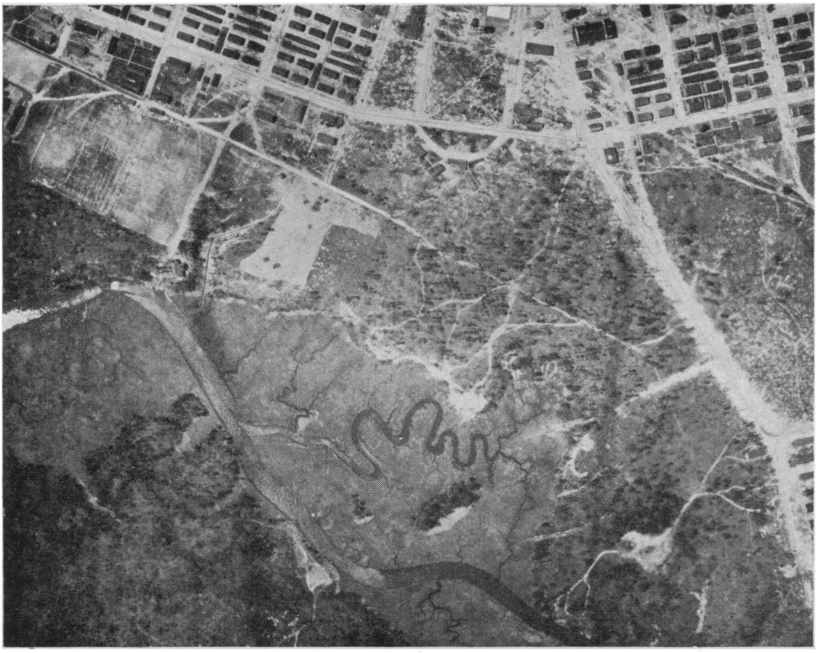


FIG. 4

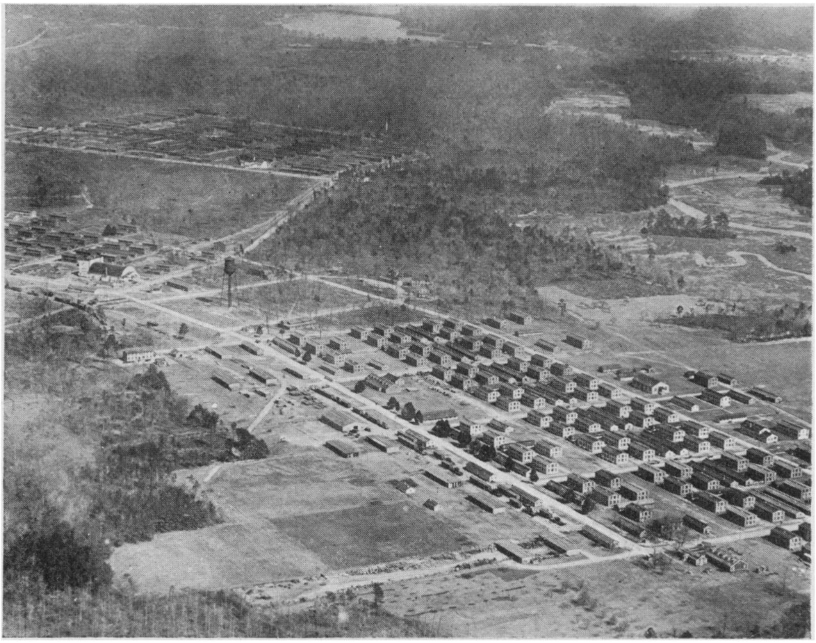


FIG. 5

FIG. 4—Vertical view of a part of Camp Abraham Eustis, Va. This is the area shown in Fig. 3, with which it should be compared. Note the differences in detail, especially as regards the drainage. (Photograph by U. S. Army Air Service.)

FIG. 5—A part of Camp Abraham Eustis, Va., showing in oblique view the area represented by Fig. 3. For orientation note that the meandering stream shown near the bottom of Fig. 3 appears here in the right hand middle ground. To correspond with Figs. 3 and 4 this one should be viewed in reverse position. (Photograph by U. S. Army Air Service.)

defense. Such details may all be obtained by aerial photography with great accuracy and relatively small expense.

To illustrate this point I have chosen the photograph of an area near Camp Abraham Eustis that was mapped with extreme care. This area was mapped on a scale of 1:10,000, or about 6 inches to the mile, and the map shows details with unusual fidelity. The area shown on the part of the map reproduced as Figure 3 was photographed both vertically and obliquely from the air. On comparison of the map with the vertical photograph (Fig. 4) it is obvious that in spite of the detailed character of the map the photograph shows many details that the map does not represent, such as the small streams in the foreground. Many of these details are too trivial to be worth the expense of mapping, but the photograph records them at no extra expense.

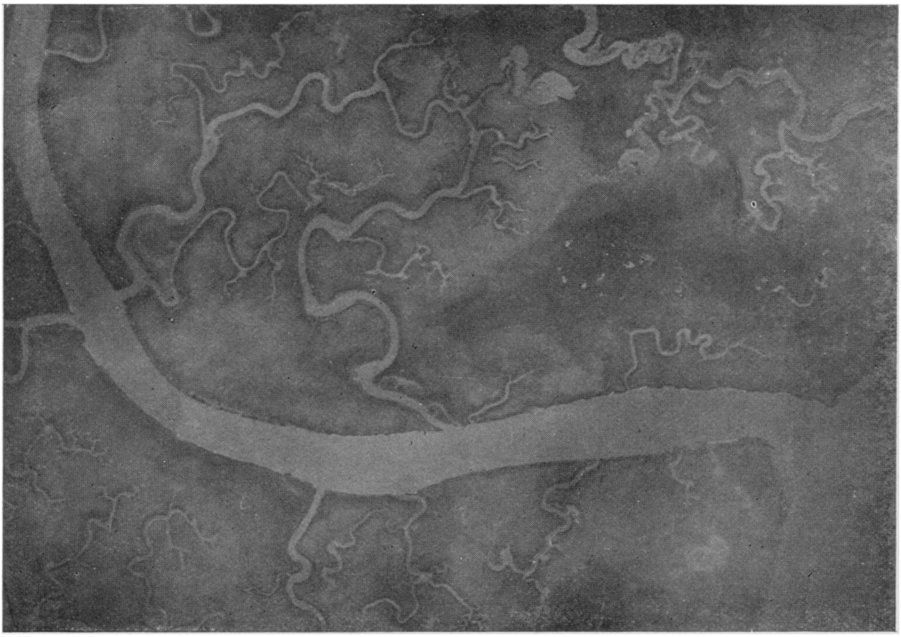


FIG. 6—A mud flat off the eastern shore of Virginia, showing channels in an area submerged at high tide and exposed at low tide. (Photograph by U. S. Army Air Service.)

OBSERVATIONS ON AREAS DIFFICULT OF ACCESS

Some of the marshes of the Coastal Plain consist of soft muck and mud through which it would be foolish to attempt to make one's way. Others are equally inhospitable jungles of reedlike grass and similar rank vegetation. It is not strange that the maps of these marshes do not show great detail. The camera, however, is not concerned with the difficulties that the surveyor might encounter. It represents useful and useless details with equal accuracy. It is somewhat surprising as well as especially interesting to note from photographs of some of these marshes that in addition to the tidal runs or so-called thorofares open at both ends, they have perfectly developed stream systems showing dendritic arrangement with complicated interlacing of branches—beautifully perfect meandering rivers in miniature, a whole system developed on an area of only a few acres.

Details of a Marshy Area

Captain Place photographed some of these marshes during a flight, but unfortunately the weather conditions prevented him from rising more than 2,000 feet, hence the photographs include only small portions of the marsh lands. Figure 7 represents a strip of land about three-quarters of a mile long in the extreme southwestern part of Lee Marsh. This figure may be compared with the topographic map of the same area. (See United States Geological Survey map of New Kent quadrangle, Virginia.) The rounded end to the left in the photograph is the relatively pointed projection of the marsh toward the southwest. The larger stream in the upper right hand corner of the photograph is the same as the one mapped as a winding thorofare through the marsh. The complicated system of drainage shown in the body of the photograph is not represented on the map, and this helps to establish one of the points here emphasized, namely, that aerial photography supplies at no extra expense geographic details which do not warrant the expenditure that would be necessary to map them by ordinary methods.

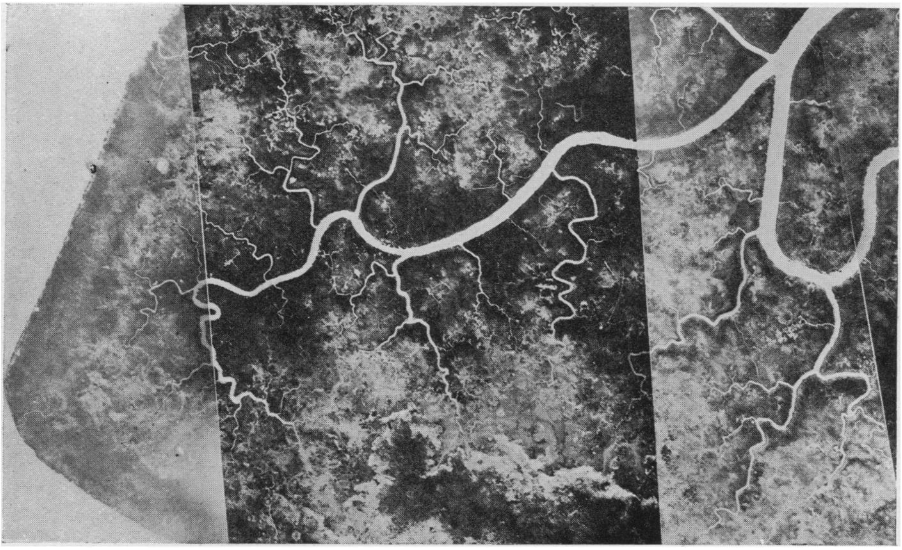
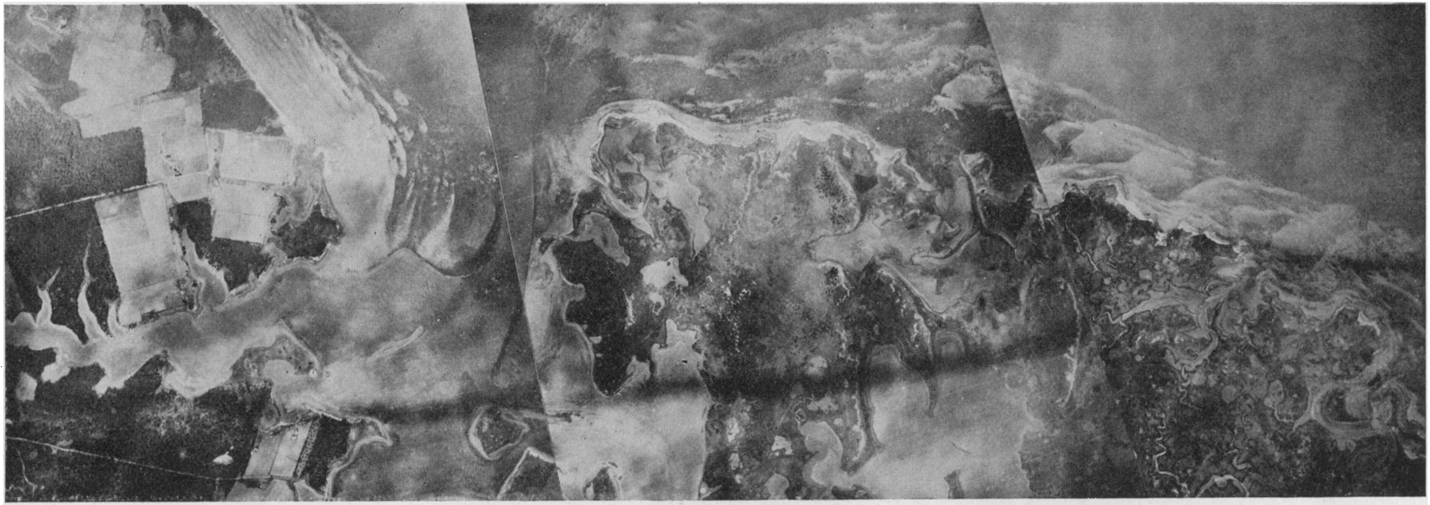


FIG. 7—Aerial view of a part of Lee Marsh near West Point, Va., showing an intricate system of drainage not indicated on existing maps. The straight lines across the illustration are due to the joining of photographic prints. (Photograph by U. S. Army Air Service.)



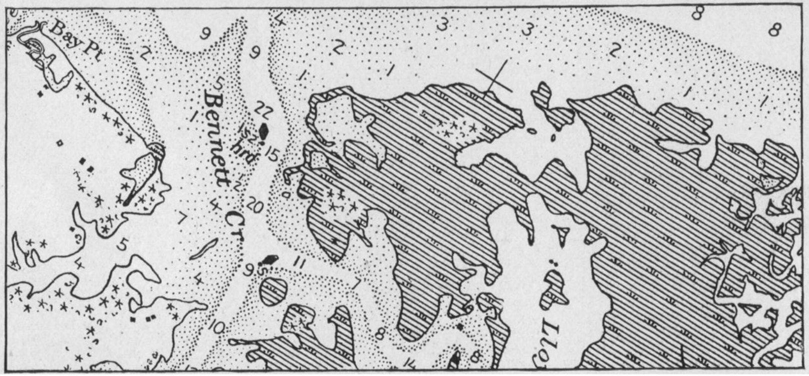


FIG. 8—Above is an aerial photograph of a section of the mouth of the Poquoson River, Va. On the left is seen forest and cultivated land; in the center and to the right marshland. Subaqueous features shown are sand bars, submerged terraces, and inner channels. Sand bars are seen as a light-colored zone of wavy appearance. Currents are longshore, and the bars point upstream. The outer edge of this zone marks the outer edge of a shelf from 3 to 5 feet deep. In the left center it is sharply cut by the navigable channel of Bennett Creek (9 to 22 feet deep) which is clearly distinguished from the submerged shelves on either side. The illustration is made up of three photographs. The diagonal lines across it are due to the joining of the photographic prints. (Photographs by U. S. Army Air Service.) Below is a reproduction of the U. S. Coast and Geodetic Survey chart of the same area.

Other places where aerial photography is useful in supplementing maps and charts are low-lying coasts that are likely to change in form during a storm and areas near the mouth of a stream that is delivering sediment. It is noticeable that in some places shore lines differ from those indicated on maps made several years ago. In some of these low-lying areas there is a wealth of detail that is utterly trivial and would seem superfluous on an ordinary map.

Compare, for example, the photographic reproduction in Figure 8 with the United States Coast and Geodetic Survey chart representing the same area. The photograph covers about a linear mile of the south bank of Poquoson River, a small tributary of Chesapeake Bay south of the mouth of York River. The portion to the right, east of Bennett Creek, is marsh land; that to the left is partly cultivated and partly wooded. In the marsh land may be seen dark-colored areas covered with vegetable growth, light-colored wet places, many minute meandering streams bordered by mud flats covered with water at times of high tide, and several unknown objects. At the left are relatively dark-colored areas of woodland and light-colored roads leading to cultivated fields near the shore. Houses and barns appear as minute dots. The low bluffs along streams appear as sharp lines bordered by a narrow belt of sand or mud exposed at low tide. The sandy beach appears white; the mud darker.

OBSERVATIONS OF SUBAQUEOUS BARS AND TERRACES

It is well known that where the water is clear objects submerged to a considerable depth may be seen from points far above the surface. During the war submarines were detected and followed by observers in airplanes, and sunken vessels have been located by aerial observation. It is said that objects in clear water at depths of 45 feet have been successfully photographed and that with the proper plates and ray filters the presence of objects invisible to the eye is revealed by the camera. It is possible to use this method of observation to some extent in detecting and mapping sand bars, shoals, drowned terraces, and channels.

Among aerial photographs taken near Langley Field, Va., several prints were found on which a dark belt appeared near the middle of a stream and lighter-colored belts between it and the stream banks. On comparing the photographs with charts of the areas represented it was found that the dark belts represent deep channels, and the light lateral belts less deeply submerged shoals.

The practical use of such a photograph is illustrated in Figure 8. The inner channel of Bennett Creek, ranging in depth from 9 to 22 feet, is used as a passageway for boats. In the photograph this channel appears distinctly set off from the less deeply submerged shelves on either side. The photograph used in Figure 9 also shows the navigable inner channel.

Some of the photographs, taken along the banks of the larger streams, show sand bars and other details of the bottom in a definite zone, beyond which the area appears characterless. Comparison of these photographs with the Coast Survey charts indicates that beyond a shallow submerged shelf there is a relatively sharp descent to deeper water. This is illustrated in Figure 8, where the outer edge of the zone of sand bars—the light-colored portions of wavy appearance just offshore—marks the outer edge of a shelf which is 3 to 5 feet below water level at low tide. In Bennett Creek, toward the left, this sand is sharply cut by the inner channel. It may be noticed that this central portion appears characterless, doubtless because under the conditions prevailing at the time the photograph was taken the lens was not able to penetrate this depth of water. At the right, however, where soundings indicate a depth of 8 feet of water, certain differences in color suggest unevenness of bottom.

The details of the sand-bar zone are worthy of special note. This area is at the mouth of Poquoson River, where the currents are longshore. These currents carry the sand and heap it up in spits and hooks, which point upstream. The open bay is toward the right, and each mass of sand tends to face toward the left, or upstream, producing a steplike aspect.

But not all the photographs showing coast lines reveal these subaqueous features. Evidently some conditions of atmosphere or water are unfavorable for photographing them. Unfortunately I was not able to ascertain the conditions under which the photographs of these submarine areas were taken. Many of those examined at Langley Field resulted from random shots made by students during practice flights, when no record of altitude or conditions of light, wind, or time of day was obtained. Furthermore, these pictures were taken for the purpose of photographing subaerial rather than submarine objects.

The Photographing of Underwater Features

As relatively little is known of the conditions favorable for photographing underwater objects, a record of certain flights on which such photographs were taken may be useful for future reference. A flight for observation was made with Captain Lawson on May 21, 1920, between 2 P. M. and 3 P. M. Over Langley field we circled to an altitude of 4,000 feet, then flew in a general northerly direction across the mouth of York River, turned eastward around Mobjack Bay to New Point Comfort, and returned over the water to the coast south of the York. Thence we followed a winding course southward over to the mouth of Back River and finally returned to Langley Field. The wind was blowing from the west with sufficient force to produce numerous whitecaps on the bay. The sky was somewhat evenly but thinly overcast, so that the light was fairly strong, but no direct rays from the sun penetrated the clouds.

Under these conditions of light, altitude, and surface of water the following observations were recorded. Over a broad zone near shore, in some places a mile or more in width, submerged objects were seen almost as plainly as objects above water. The white sand bars were particularly conspicuous. In several places three to seven of them were observed in parallel or concentric arrangement like giant ripples. Areas of dark mud and of green vegetation-covered bottom contrasted sharply with the sandy areas. Some of the dark places seemed to indicate deep water, but this appearance may have been deceptive. The roughness of the water surface, even where whitecaps were numerous, did not interfere seriously with visibility.

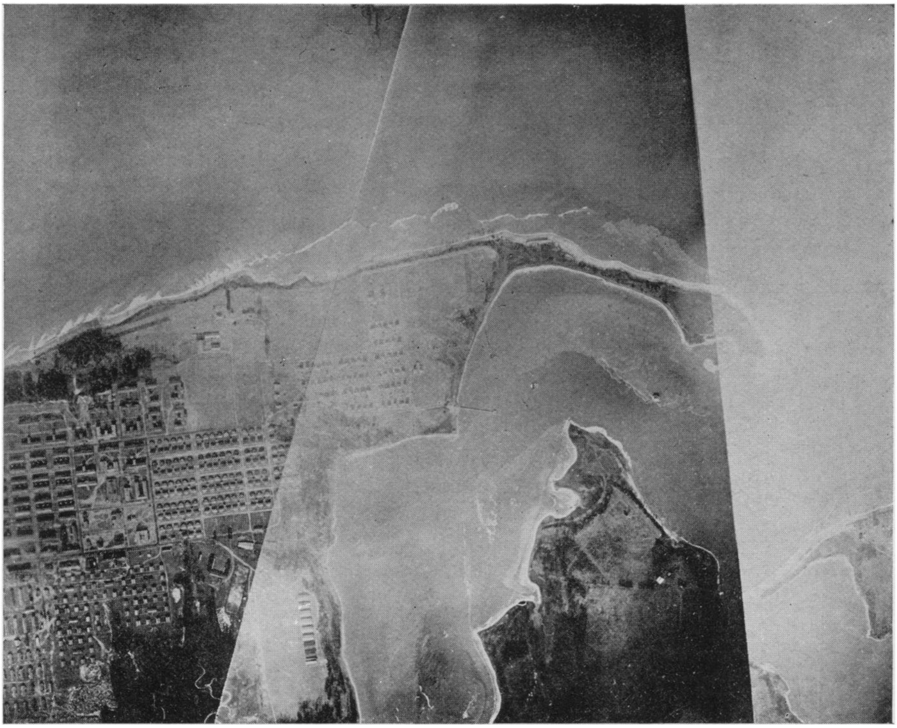


FIG. 9—Vertical view of Penniman and King's Creek, a southern tributary of York River, Va., showing navigable inner channel at the edge of which is the boat landing, marginal shoals, and sandy beach. The straight diagonal lines are due to the joining of photographic prints. (Photograph by U. S. Army Air Service.)

The submerged land forms appeared especially conspicuous in Back River, one of the so-called rivers tributary to Chesapeake Bay which are in fact estuaries where the waters of the bay occupy drowned valleys. For 3 miles or more above its mouth Back River is more than a mile wide and less than 6 feet deep, except near the middle, where a relatively narrow channel ranges in depth from 6 to 25 feet. The sinuous course of this channel is plainly discernible from the air. The outer edge of the slightly submerged shelf appears as a definite line, owing to change in slope of bottom. The boat landing at Amory's Wharf is built where the bottom descends steeply from the submerged shelf to the deep channel.

In many places on this and other estuaries the zone in which the details of bottom were clearly visible terminates at what appeared from our exalted point of observation to be a sharply defined and gently sinuous line. Most of the boat landings are at or near this line, and several beacons were seen near it. Comparison with the Coast Survey charts indicates that at the outer edge of this zone the water at low tide is about 5 feet deep. The line seemed to indicate the presence of a bench with steep outer slope, rather than a uniform slope of bottom.

In nearly all places beyond the shallow water there appeared a zone of variable width which was of a dark chocolate-brown color, darker than that near shore, but few details of the bottom could be distinguished. There are numerous fish traps and nets in this zone, many more than were observed in the shallower water. At the mouth of York River and at several places in Mobjack Bay the chocolate-colored zone terminated at a dim but plainly discernible line, beyond which the water appeared dark and characterless. Near its outer edge are the larger lighthouses such as the one at the mouth of York River off Godwin Island and those off Tow Steak Point and Wares Neck Point. The landing at Bay Side Wharf, north of New Point Comfort, is also near the outer edge of this zone. Reference to the charts indicates that the water at this landing is 12 feet or more in depth and that the lighthouses are at the outer edge of a shelf where the water is 10 or 12 feet deep. Beyond this shelf the bottom falls away sharply to deep water. It may therefore be inferred that the dark-colored characterless area near the mouth of the York River represents the deep inner channel, where the water is 25 to 70 feet deep. It may further be inferred that the dim line between the chocolate-colored zone and the dark inner channel denotes the relatively sharp descent of the bottom at the edge of a submerged shelf. These inferences, however, must be regarded as tentative and should be verified by further observations.

In studying the underwater features as shown in photographs caution and careful checking in every way possible are necessary. Changes in hue in the photograph might be due to sediment in suspension rather than to differences in depth of water. This was made obvious by the flights over the Potomac River referred to below.

Observations on the Potomac River

As the observations near Langley Field proved that shoals and channels can be photographed from the air, it seemed possible that drowned terraces and valleys such as those of Potomac River might be successfully shown in this way. To test this possibility several flights were made from Washington, D. C. Here the conditions were found to be quite different from those

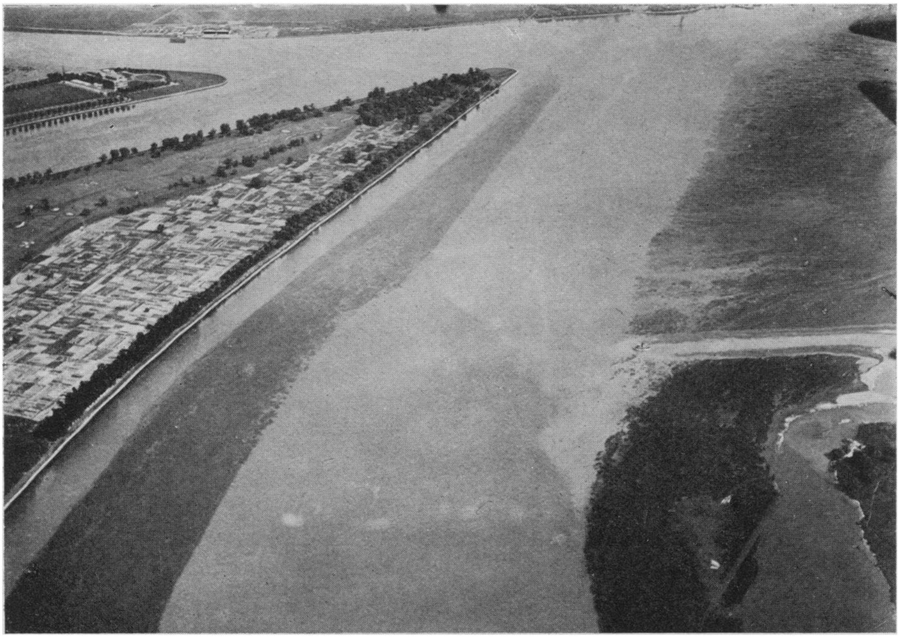


FIG. 10

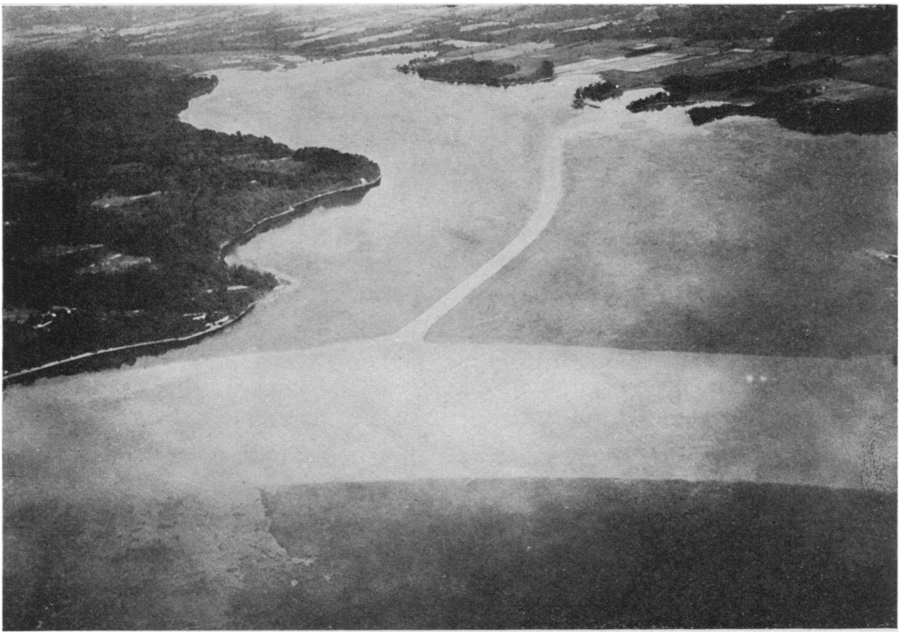


FIG. 11

FIG. 10—Potomac River and the lower end of Potomac Park at Washington, D. C., showing in the foreground the deep channel, light because of muddy water; the submerged shoal, with dark, weedy bottom showing through 2 to 5 feet of clear water; and a narrow channel 8 to 10 feet deep along the wall of the Park. The Anacostia River and Hydroplane Station appear in the distance. (Photograph by the author.)

FIG. 11—Underwater channels and shoals in Potomac River and Piscataway Creek. The channels appear light-colored because filled with muddy water. The dark shoals show through the clear water which is 2 to 5 feet deep. (Photograph by the author.)

on Chesapeake Bay. In the clear water of the bay dark color indicates depth, but in the river the deep water of the main channel was turbid and appeared light-colored (Fig. 10), while the shallow water on the broad drowned terrace was clear and appeared dark-colored because of weeds growing on the bottom. The inner channel of each tributary stream was also seen plainly (Fig. 11). Most of the tributaries entering from the hills to the west contained light-colored turbid storm water which followed the drowned channel through the clear shallow water on the dark-colored shelf to the main channel of the river. On the opposite side, where the tributaries are short and drain low land few of them contained turbid storm water. The deep inner channels here appeared darker than the drowned terrace in which they are cut. Every channel on either side was sufficiently clear to be successfully photographed. A channel filled with clear water appears in the photographic print as a dark belt; a channel filled with opaque muddy water appears light-colored. However, this light-colored portion indicates only the approximate position of the channel, because the muddy water gradually mingles with the quiet shallow water on the shelf.

Aerial Photography As an Aid to Physiographic Interpretation

The possibility of recognizing shoals and channels from a photographic print and of determining in some measure the shape of submerged land forms opens a new avenue of approach to the study of submarine geography. In some places, especially in a drowned region, aerial photography may be used with success in working out the physiographic processes that have produced the drowned land forms and thus assist in solving some vexed questions in earth history.

There is also a practical aspect of the subject, for photographic representations of shoals and channels can be used in making navigation charts and in keeping up-to-date charts of areas that undergo changes. With a photograph such as that of King's Creek (Fig. 9), a boatman should have no difficulty in avoiding shallow water. Many of the tributary channels of the Potomac and other rivers of the Coastal Plain are not charted, and some have changed since charts of them were made. Small craft on the Potomac frequently go aground where the water was supposed to be deep enough to float them. Aerial photographs showing the position of the channel in critical places might be of use.

So far as I have been able to ascertain little is definitely known of the conditions most favorable for obtaining photographs of submarine objects. It is annoyingly obvious to the aerial observer that at certain times he can see nothing beneath the surface, though at other times he can see underwater objects with great distinctness. In trying to ascertain the most favorable conditions for such observations, it was found that these objects are seen plainly when the sky is evenly overcast or when it is uniformly clear. Sometimes when the sky is only partly cloudy the surface of the water seems to act as a mirror, and nothing is seen but reflection of cloud and sky. Waves seem to have little effect on the visibility of objects beneath them except to diffuse the reflected sunlight. This reflected light is stronger than that coming from submerged objects and destroys the effect of those objects on the photographic plate. Hence to photograph underwater features successfully a time should be chosen when direct reflection of light from the sun or from a brightly illuminated cloud will not enter the lens.

Both experience in the air and experiments in the laboratory show that the best results are likely to be obtained early in the morning or late in the afternoon, under an evenly illuminated sky. But experience also indicates that there are unknown factors which affect the results. It is a puzzling fact that the photographs taken at some moments when the eye caught the image of submerged objects show only the surface of the water.

There is need of careful research to determine the conditions under which the best results may be obtained. The height and the time of day for exposure with a certain lens, the emulsion and kind of ray filter best suited under certain conditions, the effect of refraction of light as it enters and emerges from the water, and the effect of polarization are subjects demanding serious consideration.